DESCRIPTION

BEACON CHANNEL FOR FREQUENCY HOPPING WIRELESS DEVICES

FIELD OF THE INVENTION

The invention relates to devices arranged to communicate using a frequency hopping interface, and to find other devices within range, to methods of communicating between such devices, to methods of offering a location based service using information transmitted to mobile devices by these methods, to corresponding software, and to groups of access points for use with such mobile devices.

BACKGROUND

It is known to have beacon signals transmitted from base stations of a wireless communications network to enable mobile terminals to update their position. An example is shown in GB patent 2298108 relating to the CT2 air interface standard (I-ETS 300 131, Nov 1994), involving using a guard band between time division multiplexed channels to broadcast the beacon channel. More recent air interface protocols use frequency hopping techniques, and can create ad-hoc networks. An example is the well known Bluetooth™ standard, developed by the Bluetooth special interest group. This system applies frequency hopping to enable the construction of low-power, low-cost radios with a small footprint. The system supports both data and voice, applying fast frequency hopping in combination with a robust voice coding. The frequency hopping has a nominal rate of 1600 hops per second (hops/s) through the entire 2.4 GHz ISM band, which is 80 MHz wide. Devices based on bluetooth wireless technology can create piconets, which comprise a master device and one or more slave devices connected via the FH (frequency hopping) piconet channel. Slave devices can be in a parked mode to save power while still synchronised to the channel.

The standard includes provision of a beacon channel. The beacon channel consists of one beacon slot or a train of equidistant beacon slots

which is transmitted periodically with a constant time interval. The beacon channel serves four purposes according to the standard:

1. transmission of master-to-slave packets which the parked slaves can use for re-synchronization

2. carrying messages to the parked slaves to change the beacon parameters

3. carrying general broadcast messages to the parked slaves

4. unparking of one or more parked slaves.

It is known from PCT patent publication WO 0249272 to form ad hoc radio local area networks using Bluetooth, and use the beacon channel for parking portable devices in range of an anchor unit, once they have been identified as being within range, to reduce the time spent establishing and releasing connections.

Portable devices should quickly and efficiently gather data from base stations such that a mobile user is not required to undertake actions such as staying close to a base station whilst contact is established between portable device and base station, nor having to specifically initiate interaction. In the ideal case, the terminal will detect fixed beacon base stations and extract basic information from them without needing to transmit at all. However, the current Bluetooth specification does not describe this type of broadcast operation. The existing methodology for implementing a radio beacon is to perform a two-step connection process, commencing with the discovery of devices followed by the actual transmission of the information using the same device. Bluetooth requires that the discovery phase is completed before a transmission can take place. When used in a dynamic mobile environment, the time this process takes can be seconds or tens of seconds, which can often be longer than the actual time the device is in range, causing the information not to reach the client.

The frequency hopping nature of the system means that, in order for broadcast messages (or, indeed, any messages) to be received by a passing terminal, the terminal has to be synchronised to the base station in both time and frequency. It has to synchronise its clock to the base station clock and,

from the base station's identity, deduce which of several hopping sequences is being employed.

To do this, the terminal has to join the piconet administered by the base station (piconet master) as a slave. Two sets of procedures are used: INQUIRY and PAGE. Inquiry allows a device to find the address of other devices. Page allows a would-be master to invite slaves of its choice to join the piconet.

From this it can be seen that the time taken for the transaction to be completed is an issue. Due to the mobility of the clients and the typically small range of Bluetooth base stations, the time taken for a transaction to be performed can be critical. Should the time for this interaction to be performed in full (i.e. from an inquiry stage to the actual service interaction) be too long, the client will be out of range of the beacon and will not have received the service information.

Another issue is the power consumption of the mobile device. Since the mobile device is required to be compact and light, power consumption is an issue when adding additional functionality to the device. Since each transmission requires significantly more power than reception, this can quickly drain the available power from the battery of the mobile.

Many individual base stations, each performing their own inquiry will increase the total number of packets on the air, which is undesirable because it increases interference with other devices.

Since the Inquiry procedure has been invented specifically to solve the problem of bringing together master and slave, one solution shown in PCT patent publication WO 0201814 is to piggy-back a broadcast channel on the inquiry messages issued by the master. This can help get small amounts of local information such as references to shops, maps, restaurants and so on, to the portable device without the delays of setting up a connection. At the air interface, this mechanism can be entirely compatible with existing Bluetooth systems.

In PCT patent publication WO 02058331 this is extended by having the beacon device send additional data using a spread spectrum technique in the

inquiry message. This can enable more data to be sent more robustly, without the delays involved in setting up a frequency hopping connection.

To improve speed and power consumption, a split beacon technique is proposed in PCT patent publication WO 0201815 in which a first fixed beacon device is dedicated to broadcasting a series of inquiry messages. The portable device replies with an identifier which is passed on to a second fixed beacon, and the second fixed beacon carries out all service interactions. The ability of the first beacon to issue inquiry packets continuously can make the process quicker. By having the second beacon handle all interactions, the first beacon does not have to pause operation to issue page messages, nor does it have to stop to allow interactive traffic. As a consequence, the portable device never has to wait for the first beacon to enter inquiry mode, which can represent a significant time saving.

It is also known for the portable devices to initiate discovery, rather than relying entirely on listening for transmissions from fixed devices. For a mobile Bluetooth device to be constantly aware of its neighbouring devices, it can discover them by regularly inquiring, e.g. the Periodic Inquiry process as set out in the current Bluetooth specification.

This Periodic Inquiry process involves transmitting sequences of ID packets of at least 1.28s in length at average intervals of at least 3.2s, successive packets being transmitted on different frequencies. A response window is provided between each packet. Any device in inquiry scan mode which is listening on one of the frequencies can make use of the next response time slot to send an FHS (frequency hopping and synchronisation) packet. Since each response window allows only one response, a random backoff scheme introduces an average delay of 320ms to make use of a later response window and reduce the likelihood that FHS packets from different device collide with each other.

Periodic Inquiry is not a practical solution for most mobile Bluetooth devices as constant, repetitive use of inquiry will produce significant interference to other Bluetooth devices and can lead to excessive loading of scanning devices.

An example of this excessive loading is as follows. Scanning devices listen for one ID packet, backoff for a random interval then if they hear a second ID packet, reply with an FHS packet. They then immediately return to scan mode and the process repeats. This repetition ensures that every period of inquiry generates a series of FHS packets at different times and frequencies. Unfortunately, if a scanning device receives an ID packet every time it listens for one, as can happen if another master device is within range, it can become trapped in this sequence. Where constant detectability is desired, and where there are a number of Bluetooth devices performing periodic enquiry, the problem of scanning devices being trapped in a loop is magnified.

SUMMARY OF THE INVENTION

It is an object of the invention to provide improved apparatus or methods, addressing such problems. According to a first aspect of the invention, there is provided: a first device for communicating with other devices using a frequency hopping wireless interface, the first device being arranged to send a sequence of messages each on a different frequency, for finding other devices within range, and being arranged to listen for a response during a subsequent response window, on one or more response frequencies, being a subset of less than all possible response frequencies, and to receive return information from the other devices without needing to set up a frequency hopping connection, the response window having a duration sufficient to receive more than one response.

By sending a number of messages, then providing a longer response window, long enough for multiple responses, rather than one message then one response, the process can be faster than before. This is partly owing to less time being wasted by guard bands between transmit and receive time slots. More notably, the other devices can have much shorter backoff times, than those of the known Bluetooth periodic inquiry process, as they need not wait until they have detected another message from the first device. The reduced number of response frequencies can save the mobile device from

needing to listen to all the frequencies, which can save time and reduce the number of guard bands between time slots for listening to each frequency. This can enable the response window to be kept shorter. The combination of features gives a good chance of a response being received in the first available response window, and hence the overall time for short transactions such as a single request and response for device discovery, can be kept short. This in turn leads to low power consumption and low chance of interference between devices. Also, as the other devices can respond more quickly, an interval between sequences of the messages can be increased, thus lowering the total amount of packets broadcast, and lowering the amount of processing at the first device, all of which helps save power consumption. Also, the scanning mode trap can be avoided as there is no need for the other devices to return to the scanning mode.

As an additional feature of some embodiments, the sequence of frequencies of the messages is predetermined and related to the time of the start of the response window. This can enable the start of the window to be determined by the other devices.

As an additional feature of some embodiments, the first device is a mobile device. If the mobile device initiates the finding process, the fixed base stations need not transmit when there are no mobiles in range. Also mobile devices benefit greatly from the measures which keep the power consumption low.

As an additional feature of some embodiments, the sequence of messages has an indication of a response channel. This can make it easier for the other devices to calculate which frequency to use for the response, and the response frequency can be varied to ensure even use of spectrum. The overall time for short transactions such as a single request and response for device discovery, can be kept short, which leads to low power consumption and low chance of interference between devices.

As an additional feature of some embodiments, the return information includes received signal strength information from the other device or devices. This can be useful for deciding when to handoff.

As an additional feature of some embodiments, the return information includes location information from the other device or devices. This can be useful for "context aware" or location based services.

As an additional feature of some embodiments, the return information includes frequency hopping and synchronisation information. This can enable more information to be exchanged using a conventional frequency hopping technique.

As an additional feature of some embodiments, the wireless interface is compatible with Bluetooth.

As an additional feature of some embodiments, the other device is a network access point. This can enable a mobile device to roam across a wide area fixed network.

As an additional feature of some embodiments, the response frequency indication comprises a four bit code. This can indicate one of 16 frequencies or groups of frequencies. In the latter case, the actual frequency and the response window start time can be determined by the other device with other information such as the frequency at which the message was received.

As an additional feature of some embodiments, the response channel indication is altered cyclically. This enables more even spectrum use.

As an additional feature of some embodiments, the first device has a mobile phone or mobile personal computer. This can enable such devices to receive and use local information for context aware services.

A second aspect of the invention provides one of the other devices for use with the first device of any preceding claim, the other device being arranged to listen for one or more of the messages, to determine a time of the response window after the sequence of messages, and to send return information on that response frequency to the first device without needing to establish a frequency hopping connection.

As an additional feature, the messages include an indication of a response channel, and the other device is arranged to determine the time of the response window using the indication.

A third aspect of the invention provides a method of communicating between a first device and other devices having a frequency hopping wireless interface, the method having the steps of:

sending from the first device a sequence of messages each on a different frequency, for finding other devices within range,

listening at the first device on one response frequency or on a subset of less than all possible response frequencies, during a response window having a duration sufficient to receive more than one response.

determining at each of the other devices in range, a time of the response window after the sequence of messages, and

sending a response during the response window, from each of the other devices in range, to the first device, containing return information without needing to set up a frequency hopping connection.

A fourth aspect of the invention provides a method of offering a service on mobile devices, using return information sent to mobile devices by the above method, where the first device is a mobile device.

This is claimed explicitly in case the added value of services enabled by the devices or methods is much greater than the value of the devices or methods.

A fifth aspect provides a group of access points, each incorporating an other device, and coupled to provide location information, or access to other telecommunications networks. This group could provide widespread coverage and be owned or run by an operator and become a very valuable piece of infrastructure, critical for value-generating services.

A sixth aspect provides a first device for communicating with other devices using a frequency hopping wireless interface, the first device being arranged to send a sequence of messages each on a different frequency, for finding other devices within range, the messages including an indication of a response channel, and being arranged to listen for a response during a subsequent response window, on one response frequency, and to receive

return information from the other devices without needing to set up a frequency hopping connection.

Features can be in the form of software for running on or defining the operation of conventional firmware or hardware such as microprocessors, digital signal processors, application specific integrated circuits and so on. Any of the additional features can be combined together or with any of the aspects of the invention, as would be apparent to those skilled in the art. Other advantages may be apparent to those skilled in the art, especially over other prior art not known to the inventors.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described by way of example, and with reference to the accompanying drawings, in which:

Fig 1 shows a prior art arrangement of mobile devices coupled to networks via access points to which embodiments of the invention can be applied;

Fig 2 shows an overview of a beacon channel process according to an embodiment of the invention;

Fig 3 shows an overview of mobile and fixed devices using the beacon channel sequence according to an embodiment of the invention;

Fig 4 shows message and response window timing according to an embodiment of the invention;

Fig 5 shows message format according to an embodiment of the invention;

Fig 6 shows frequency sets for the messages of an embodiment of the invention;

Fig 7 shows a frequency selection scheme according to an embodiment of the invention;

Fig 8 shows a beacon channel structure according to an embodiment of the invention; and

Fig 9 shows a response packet according to an embodiment of the invention.

DETAILED DESCRIPTION

Embodiments of the invention will be described with reference to the Bluetooth specification, though it will be apparent that it is applicable to other frequency hopping wireless interface standards. One use for the embodiments is to provide constant location awareness in a network such as a Bluetooth Network Access Point (NAP) network, for example, in a power-efficient manner. It can allow mobile Bluetooth devices to know which NAP they are nearest and gain network information quickly and with a minimum of effort, without requiring a connection to any NAP. The Beacon Channel described below is also appropriate for exchanging more detailed geographical information through the Local Positioning profile.

Handset operation involves 20ms duration poll/response sequences, including a self-contained backoff procedure to avoid response collisions. The fixed Bluetooth NAPs are arranged to scan with a higher duty cycle than previously used, to make the system as fast as possible. The Beacon Channel is notable for low latency, low handset power usage and a low level of on-air packets. There are a number of uses for some basic level of data communication between Bluetooth units prior to or instead of connection establishment. Personal Area Networking (PAN) could be enhanced by use of connectionless data exchange in order to assist in connection set up and maintenance, including handoff. In particular, a PAN User device must be constantly aware of which NAPs are in connection range. The Beacon Channel provides an operating mode new to Bluetooth which can be used for PAN. Also, Local Positioning procedures for location based services can be improved by using the beacon channel rather than normal Bluetooth connections for exchanging geographical position data with APs. This improvement is particularly noticeable where there is a need for checking position at regular short intervals. The Beacon Channel can provide improvements in exchange time, privacy and system loading.

A view of a known set of devices to which embodiments of the invention can be applied is shown in Figure 1. It consists of a number of fixed Bluetooth

Access Points AP1 to AP3, in a given area, some of which may be connected together forming networks. Mobile Bluetooth devices MD 1 to MD 3, move around in this area, and need to be constantly aware of neighbouring devices. A backbone couples the access points to external networks 40 and an example of a communication destination or end point 50, such as an internet server for example.

Figure 2 Overview of Beacon Channel sequence:

This figure shows a sequence chart of some of the main steps. The left column shows actions of the first device, while the middle and right columns show actions of two of the other devices. As shown, the first device can be a mobile device MD1 and the other devices can be fixed base stations such as network access points AP1,AP2. At 100, the first device sends a sequence of messages at different frequencies, then at 102 listens for responses during a response window, at a response frequency. At 104, it reads the return information in the responses, and uses the return information. If it is location information, then the device can update its position or use the information for location based services. The first device then sleeps at 106 then repeats this process every few seconds or minutes as appropriate.

The other devices (identified in the figure reference numerals by suffixes A and B respectively) listen (108A,B) at respective frequencies (f1,f2), receive (at 110A,B) respective ones of the messages, determine (at 112A,B) a response frequency, and determine a timing of the response window. They send (at 114A,B) their response within the window, after a random backoff period, then return to the listening state (at 116A,B).

Applied to the Bluetooth standard, the Beacon Channel allows mobile Bluetooth devices to regularly discover other devices by using ID (i.e. Inquiry) packets with a specially reserved Access Code (the Beacon Access Code or BAC) and an additional 4-bit Response Channel Indicator.

The mobile devices transmit short groups of (BAC based) ID packets at regular intervals, each group being followed by a short scan window. These ID

packets include the Response Channel Indicator (RCI) and are identified with the label ID+.

When each scanning Access Point receives the ID+ messages, they respond with "Beacon" (BEA) packets sent on the channel given by the RCI. The packets may contain the same data as in FHS to allow connections to be created, or else carry user data (e.g. PAN network data).

There are several benefits of using the Beacon Channel for obtaining data from NAPs.

- Coexistence concerns are kept to a minimum as the number of on-air packets has been kept as low as possible. Additionally, as the mobile devices start the procedure, an empty network of Access Points produces no traffic.

- Power usage in the mobile devices has been kept to a level comparable with normal page and inquiry scanning by specifying a low duty cycle operation.

- It is a more efficient procedure than Periodic Inquiry from the point of view of the processing required in mobile devices.

Figure 3 shows an overview of access points and mobile devices using the beacon channel process. Three of the access points are networked, another is a standalone access point in this example. Mobile devices shown include a personal digital assistant (PDA), a mobile phone, and another handset. The PDA is transmitting message sequences, but is not within range of any of the access points. The Handset has already found two access points in range and is receiving return information such as an FHS packet to enable it to set up an FH connection to receive large amounts of information. The mobile phone is transmitting a message sequence and receiving an FHS packet. In principle, the mobile devices can also act as listeners, be found by other mobile devices, and pass on whatever return information such as location information, or other control information such as hopping sequences, timings, device identities and so on, which they have obtained previously from fixed devices. This type of ad hoc networking can extend coverage and reduce the need for an operator to invest in fixed access points.

As shown in the timing chart of Figure 4, the Beacon Channel in the mobile device includes a sequence of 16 messages followed by a response window, taking up about 20 milliseconds. This is transmitted repeatedly at intervals termed the beacon_interval. In most cases, this value is best chosen as a few seconds. It includes a random element to prevent Mobile Devices repeatedly overlapping each other. An example of suitable limits are shown in table 1 below.

Parameter	Calculation	Values
$T_{average\_interval}$	$T_{average\_interval} = N*1.28s$ $1<=N<=255$	Range: 1.28 - 326.4s Default: 1.28s

$$(T_{average\_interval} - 0.32) < beacon\_interval < (T_{average\_interval} + 0.32)$$

TABLE 1

The Beacon Channel consists of two parts, first transmitting a series of ID+ packets, then scanning for returned messages. The ID+ packet is shown in Figure 5 below, with or without the RCI (response channel indicator) field. It consists of a 4 bit preamble followed by a 68 bit sync word. Last is either a 4 bit trailer, or the additional RCI field which indicates the common response frequency channel on which devices should respond. A sequence of 16 ID+ packets are sent as a train at half slot intervals. This train may be optionally repeated a total Nbeacon_repetitions times. The more packets that are sent, the more likely it is that a response comes back. The calculation is shown in table 2.

Parameter	Calculation	Values
$T_{beacon\_repetitions}$	$T_{beacon\_repetitions}= N$ $1<=N<=4$	Range: 1-4 repetitions Default: 1

TABLE 2, beacon repetition calculation

As for standard inquiry procedures, it is assumed that 64 frequencies out of the 79 available are available for the Beacon Channel. Half the set is used for transmissions from the Mobile Device, and half by the Access Point. The

Mobile Device again splits its allocation into two parts, the A and B trains. Unlike with the A and B trains of normal inquiry, this grouping is fixed and does not change with the value of the Bluetooth clock. This leads to the arrangement of channels shown in figure 6 (from this, suitable frequencies used can be calculated using the BAC).

In order that all frequencies are used equally, the following selection procedure is used.

Channel used = (m+(k*16)+N)mod 32 +(X*32)

m = position in sequence, 0 - 16

k = set selector: 0 (set A)

1 (set B)

N = Interval Counter, 0-15

X = Rx/Tx switch: 0 (Tx)

1(Rx)

The A and B trains are selected alternately for each beacon interval, and the order in which the frequencies are used is cycled each time. The response frequency is always referred to the first frequency of the set. If set A contains channels 1 to 16 as indicated in Figure 6, then the first time it is transmitted then the frequencies are used in order. The first transmit frequency is 1, so 33 is used as the corresponding response frequency. The RCI value is 1 for this message. This is shown in Figure 7.

At the next beacon interval, the B train is used in a similar way. The third row of figure 7 uses set A again, but now the sequence has been cycled to start on channel 2. The corresponding response frequency is 34. The RCI indicator would be 1, so that a listening device can determine the state of this cycling, and determine the timing of the start of the response window, and the response frequency.

After the ID+ packets have been transmitted, the Mobile Device switches to scan on a single frequency for the duration of beacon_window. During this time, all Access Points which received an ID+ packet are expected to respond with FHS packets. The value was calculated to accommodate the backoff procedure described below for the Access Point.

beacon_window = (backoff length + default Mobile transmit time + default AP transmit time) = 25slots +8slots +1slot = 21.25 ms

The appropriate scanning frequency is worked out directly from the RCI of the received inquiry message. The Access Point must scan for the BAC contained within ID+ packets, then transmit response BEA packets using the frequency channel as read from the RCI. A useful feature of the Beacon Channel is that the Access Point should scan for as much time as possible. It is the trade-off between Access Point scan time and the number of ID+ transmissions which keeps latency low for the system. An optimum Access Point would have a separate channel dedicated to correlating to the BAC.

As shown in figure 8, to ensure even spectrum use the Access Point should cycle to a new scanning frequency every 2.56s, alternating A and B trains each time. On receipt of an ID+ packet, the Access Point pauses for a randomly calculated backoff time, then transmits a series of repeated BEA packets back to the mobile device at intervals of 312.5μs. The BEA packets are shown in figure 9. These contain the same fields as normal FHS packets, but without the usual 2/3 FEC (forward error correction) protection. A 72 bit access code is followed by a 54 bit header. The normal 160 bits of FHS data such as parity bits, clock , BD_ADDR, mode flags etc, may be replaced with alternative fields at the discretion of the Access Point. In particular, PAN NAP segment identities or LP position estimates could be given. BEA response packets are repeated according to $N_{FHS\_repetitions}$ calculated as shown in table 3.

Parameter	Calculation	Values
$N_{FHS\_repetitions}$	$N_{FHS\_repetitions} = N$ $1 <= N <= 4$	Range: 1-4 repetitions Default: 1

TABLE 3

The beacon_backoff time is significantly shorter than the backoff used for Bluetooth inquiry procedures, and is calculated as shown

beacon_backoff = (8+(N/2)) * 625 μs

0 <= N <= 51

This effectively gives 52 different backoff values distributed at one half-slot intervals. The further 8 slot offset ensures that no responses are generated before the Mobile Device has moved into the scan state.

As has been described above, a mobile device for communicating with other devices using a frequency hopping wireless interface such as bluetooth, sends a sequence of messages each on a different frequency, for finding other devices within range, and listens for a response during a subsequent response window, on one or more response frequencies. It receives information such as location information from the other devices without needing to set up a frequency hopping connection. The response window is long enough to receive more than one response. The overall time for short transactions such as a single request and response for device discovery, can be kept short. This in turn leads to low power consumption by mobile devices and low chance of interference between devices. An interval between sequences of the messages can be increased, thus lowering the total amount of packets broadcast. Other variations and examples within the scope of the claims will be apparent to those skilled in the art.